National Centre for Energy Systems Integration (CESI)

Interdisciplinary Research for Energy Systems Integration:

Understanding and promoting good practice

**Project FFC1-022:**

**Final Report and Recommendations**

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**Executive Summary and Recommendations**

**Introduction**

This is the final report on the National Centre for Energy System Integration (CESI) Flex Fund Project *Interdisciplinary research for energy systems integration:**understanding and promoting good practice* (FFC1-022). The project has undertaken original research on the practice and outcomes of energy systems integration research. It has also developed good practice recommendations for interdisciplinary research on energy systems integration, both within CESI and the broader whole energy systems research community in the UK. Research carried out for the project has included:

* A desk-based international *literature review* of energy systems integration (ESI) research design and methods, including peer-review journal papers and grey literature (Silvast et al., 2019).
* Three researcher and stakeholder *workshops.* The first workshop (n=13) was an internal event to discuss experiences within CESI. The second workshop (n=25) involved researchers drawn from both CESI and the UK’s wider interdisciplinary energy research community to discuss and compare experiences. The third and final workshop (n=c.50) reported early project findings, and engaged more widely with stakeholders and researchers on energy systems integration research in the UK.
* Semi-structured *interviews* with 15 senior researchers and stakeholders involved in interdisciplinary energy systems research in the UK. The interviews provided insights on the detailed experiences and views of those involved in developing and using interdisciplinary research on energy systems in the UK

In terms of its analytical approach, the project was informed by the interdisciplinary studies research field (e.g. Frodeman et al., 2010). In particular, it addressed two related concepts in interdisciplinary energy research: 'whole energy systems' (WES) research and ‘energy systems integration’ (ESI) research. This drew on the 3-fold characterisation of WES research devised by Winskel (2018):

* *intellectual diversity*: WES and ESI research initiatives typically include diverse academic disciplines, spanning different theories, data, methods, and forms of evidence. Working across these diverse knowledge bases is a defining challenge interdisciplinary initiatives.
* *integration*: unlike more loosely coupled ‘multidisciplinary’ research, WES and ESI research initiatives typically aim at integrating and synthesising the work of academics from different disciplines to develop shared research outputs. In interdisciplinary studies research, this integrated form of interdisciplinarity is seen as particularly challenging.
* *transdisciplinarity:* WES and ESI research initiatives may have a strong level of engagement with non-academic stakeholders, including businesses, policy makers and wider publics. For more ‘transdisciplinary’ oriented research initiatives, non-academic stakeholders are viewed as active research collaborators, co-designers and co-producers, rather than passive research users or less deeply engaged advisors.

**Research Findings**

## Definitions and scope

Interviews and workshop research carried out for this project suggests that a broad distinction can be drawn between ESI research and WES research, in terms of their research scope and foci. Typically, ESI is seen a more technical research framing, oriented towards engineering and physical sciences perspectives, and aimed at understanding how different parts of the energy system may be integrated, without necessarily addressing broader issues. By contrast, WES research tends to take a wider view, encompassing societal and behavioural factors, and perhaps with a greater emphasis on social science.

This suggested distinction means that ESI research agendas can be understood as a subset of WES agendas, able to offer a more detailed, focussed analysis of particular issues:

*‘Energy systems integration effectively is a subset of whole energy systems … integrating different parts of either systems or different vectors, or looking at … regional or local … energy systems.’*

A senior manager in a UK Government research funding body

There are also suggested complementarities between WES and ESI research, with ESI analysing detailed system interactions while WES research provides a broader, contextual framing. At the same time, there are concerns about the risk of weak links between more focussed ESI research and broader WES research.

## Research aims and designs

For effective interdisciplinarity in ESI and WES initiatives, overall research aims need to be open enough to meaningfully engage different disciplinary perspectives, but also well-focussed enough to enable useful outcomes. A Centre-wide integrative initiative such as a major scenarios exercise or a collaborative writing project can help resolve interdisciplinary problems in a pragmatic, productive way.

### The role of modelling

Modelling is often seen an essential feature of interdisciplinary research on energy systems because it enables integrated analysis of a complex system, helping to identify key research or strategy issues. At the same time, models – particularly the use of several different models in a large interdisciplinary research initiative such as CESI – can obscure understanding and create barriers to integrated analyses.

One concern is that modelling for ESI research tends to reflect engineering and economic research frameworks, and marginalise other disciplinary perspectives. Another concern is the abstractions involved in modelling, and the need for strong feedbacks between system modelling and ‘real world’ data from implementation trials:

*‘The UK’s almost been modelled to death … we need the learnings from delivery built back into academia.’*

A modelling expert in industry

### Research scope and disciplinary range

There are risks that a technical and engineering emphasis within ESI research may lead to a rather narrow research scope, possibly overlooking important social, behavioural and political aspects of change (for example, in personal transport, or rescaled power systems). Fully addressing these societal issues may require broad disciplinary participation:

*‘My fear would be that the energy systems integration approach just takes where we are today and says, how do we adapt what we’ve got today?*

A former senior manager in an energy research organisation

### Research integration

ESI research faces the challenge of combining qualitative and quantitative research from different disciplines into an effective ‘mixed methods’ overall design. Although quantitative methods are a critical part of ESI research, a sole emphasis on quantification can lead to research biases and omissions:

*If we always only put into scenarios what we can quantitatively describe … with our models … we … put into the background things that we know to be very important.’*

A senior interdisciplinary energy system researcher

**Novelty and Consolidation**

One challenge for developing integrative designs is that research funding and publication incentives tend to favour novelty – for example, encouraging the building of new models rather than model integration, consolidation and verification by improving links between existing models, updating or archiving data, or reviewing past findings:

*‘Working to help somebody else improve the quality of the data in their model, or make sure that models … or researchers interact with each other just isn’t rewarded.’*

A modelling expert in industry

### ESI research in practice

ESI research faces a number of practical challenges, many of which reflect the challenges of interdisciplinary research in general, rather than whole systems energy research specifically. These challenges include: persistent institutional and professional barriers; disciplinary-based research commissioning and assessment procedures; and a tendency to spread funding very thinly across a large numbers of investigators and researchers (‘salami-slicing’), especially for senior staff.

Another widely agreed issue is the extra time and effort involved in developing cross-disciplinary understandings. In practice, effective interdisciplinary collaborations often rely on pre-existing relationships, or be seen in the later stages (or second phase) of a 5-year research centre. In addressing this challenge, one suggestion is to focus on developing interdisciplinary relations at an early stage of the research cycle:

*‘Often planning of collaboration doesn’t happen at an early enough stage … you want to have that in mind and have good relationships between people before the proposals even goes in.’*

A senior CESI academic

### Early career researchers

Interdisciplinary research presents a dilemma for early career researchers: while they are often productive and enthusiastic interdisciplinarians (because they are less entrenched in disciplinary structures and are more able to devote the time and effort needed), they also face particular risks, given the professional and institutional barriers involved.

*‘For early career researchers, there are higher risks … [once] you’re already established … you can … put on hold the need for fundamental progress or original research in your own discipline to some extent.’*

A senior manager in a UK Government research funding body

## Leadership, facilitation and participation

Leadership in interdisciplinary research needs to invoke confidence in the researchers that cross-disciplinary collaborations will pay off in a valuable way. There is also a key role for non-specialists who can work across disciplinary boundaries. A frequently encountered challenge in WES and ESI research is fostering constructive interdisciplinary relations across the physical and social sciences. One reported issue here is that engineers and physical scientists may see the role of social scientists in rather limited terms – for example, as helping achieve social acceptance – rather than contributing to research designs, methods and practice on a more equal basis.

Non-academic stakeholders can play important and varied roles in WES and ESI research projects – for example, in terms of asking challenging questions, and helping ensure that academic research has wider societal relevance and value:

*‘You’re more likely to ask and answer interesting questions if you get challenged from people who see the world in different way.’*

A Professor in energy policy

### The need for improved cross-centre learning

In responding to the challenges of interdisciplinary WES and ESI research, and developing good practice, there are untapped opportunities for different research initiatives to draw on each other’s experiences. There is also scope to translate research and demonstration findings from particular initiatives such as CESI for learning across the UK’s whole energy system research community:

*‘‘I haven’t … [seen] any evidence to suggest that there’s been any kind of deliberate kind of learning, cross-consortium learning’*

A Professor with expertise in energy system modelling

# Good Practice Recommendations

## Recognise ESI research as a distinctive form of WES research

Energy Systems Integration (ESI) research is a distinctive form of WES research, with particular aims, scope and intended contributions. To date, much ESI research internationally has tended to reflect a predominantly techno-economic and engineering-based disciplinary view of whole energy system change, although more recent ESI initiatives such as CESI have taken steps toward greater diversity in terms of disciplinary participation and research strategy.

Recognising this distinctiveness is important in judging the effectiveness of ESI research strategy and outputs, yet research for this project suggests that this distinction is poorly understood among energy researchers, stakeholders and funders. The relationship between ESI and WES research in the UK needs to be more clearly defined and articulated. There is also a need for greater clarity on the contribution of individual initiatives within UKRI’s whole energy systems research portfolio.

## Decide on interdisciplinary **ambition and participation**

While there is no single best practice blueprint for effective interdisciplinary research, it is useful for interdisciplinary research centres to be explicit about their interdisciplinary ambition, in terms of developing centre-wide integrated research output and the extent of co-design and/or co-production with non-academic stakeholders. Collaborations across disciplinary boundaries take time to nurture, and different levels of ambition imply different research designs, effort and time commitment from researchers and managers, and different resource needs. Centre-wide research integration requires a significant commitment of resources and leadership effort.

Perceived failings in interdisciplinary initiatives may relate to unrealistic expectations. It is useful to set out, early on, the nature and extent of interdisciplinary ambition, drawing on wide experiences, while also allowing some flexibility given that research programmes develop and change over time.

More explicit consideration should also be given to what is an appropriate disciplinary balance for CESI, in terms of its ability to deliver its research programme. Disciplinary make-up will condition the forms of whole systems interdisciplinary research that CESI can undertake. For example, as a form of whole systems interdisciplinary research oriented towards the engineering and physical science disciplines, it may be seen as less appropriate for ESI consortia to aim for an even balance of broad disciplinary representation than seen in some other WES initiatives in the UK.

## Draw on wider experiences and expertise

Devising, implementing and regularly reviewing interdisciplinary progress should be an explicit part of CESI’s overall research strategy. CESI’s International Scientific Advisory Board (ISAB) currently offers some guidance for interdisciplinarity in CESI, but consideration should be given to strengthening the advice and support from those with similar experiences of co-ordinating large interdisciplinary research programmes in the energy systems research community, and also more widely across the interdisciplinary studies research field.

## Recognise the trade-off between flexibility and integration

A strong emphasis on flexibility, openness and diversity in research centre strategy can erode capacity for more ambitious forms of interdisciplinarity which rely on close understanding, familiarity and trust. Research for this project and elsewhere suggests that energy system integration research can involve different disciplinary and strategic approaches: either a relatively limited disciplinary spread with an emphasis on research integration, versus a more diverse disciplinary mix, with less tightly coupled interdisciplinary relations. It is important that this trade-off is recognised and anticipated by interdisciplinary research leaders and managers – and also research funders and assessors. For example, CESI has shown an awareness of this issue in the way it has designed different rounds of its Flex Fund, with an emphasis on openness and diversity in early rounds, and consolidation and integration in later rounds.

## Allow for the extra time and resources involved

As is now widely acknowledged in interdisciplinary studies research, successful interdisciplinary research requires additional time, effort and resources. This needs to be acknowledged in the design and funding of ESI research initiatives, especially in the early stages. As well as disciplinary experts, there is an important role for interdisciplinary leaders and translators – and dedicated effort on integrative knowledge production across specialisms. While there may be less capacity to respond to these challenges in the later stages of research programme, it may be possible to direct flexible funding to support integration – as CESI has shown, and it is important that funders allow use of flexible funds to support integration as well as diversity.

**Develop a systemic interdisciplinary research strategy**

CESI should maintain an interdisciplinary research strategy across *researcher, project, theme,* and *programme* levels. The overall interdisciplinary research strategy should be regularly reviewed. Suggested elements in this strategy are:

* At the *researcher level*, offer interdisciplinary publishing opportunities by negotiating interdisciplinary special issues of high-impact journals. Researchers also value CESI-run events and networks which create a protected space for interdisciplinary exchange.
* At the *project level*, devise and commission projects which deliberately and explicitly combine together different methods and perspectives, with dedicated review processes for assessing the interdisciplinary credentials of proposals.
* At the *workpackage level,* each WP should be designed have senior involvement from different disciplines. Meetings should be regular within WPs, with occasional initiatives across WPs to share best practices. WP progress in interdisciplinary research should be regularly reviewed.
* At the *programme level*, fostering interdisciplinary capacity through ‘seed-corn’ funding, and running workshops and conferences designed can promote centre-wide interdisciplinary exchange. However, developing centre-wide research integration requires a significant commitment to ‘flagship’ projects aimed at involving the majority of the centre’s researchers, disciplines and methods.

Conventional research metrics, such as journal prestige or citation patterns are less appropriate for assessing interdisciplinary research. Other forms of assessment should also be used, such as impact case studies, interdisciplinary output counts, and evidence of follow-on funding.

## Develop best practice across the energy research community

Alongside senior researchers, research funders and assessors have a critical role in shaping interdisciplinary practices and outcomes. Different forms of research commissioning, funding and design have been adopted for different initiatives within the UK’s WES research portfolio, and there is now a considerable body of experience of operating WES and ESI research centres and initiatives. There is an opportunity to review the effectiveness of these different forms, and facilitate regular exchange between different initiatives.

Research carried out for this project suggests that many of the challenges faced by CESI closely resemble those confronted other interdisciplinary centres – reflecting the similar aims of such centres, and the wider structural origins of the challenges they face. Recent steps have been taken to establish links across different initiatives, but these are not yet well embedded in the strategies and practices of the UK’s interdisciplinary energy research community.

**Assessing CESI’s interdisciplinary achievements**

**Introduction**

Winskel (2018) offered a framework to comparatively assess whole systems interdisciplinary research centres, using four characteristic elements of such research: diversity, flexibility, integratedness and transdisciplinarity. Using these criteria, assessments can be made of different centres on a broadly consistent basis, so that a ‘high’ flexibility rating indicates that a substantial proportion of the overall centre funds are allocated on an open and competitive basis; a ‘high’ integration rating indicated research processes and outputs that encompassed the majority of the research staff involved; and a ‘high’ transdisciplinarity rating indicates that non-academic stakeholders are significant contributors to the research programme

Research undertaken for this project in 2019, and follow-up discussions with senior CESI staff in 2020, suggests that by mid-2019 (around mid-way through its five-year research programme 2019) can be tentatively assessed as having a relatively medium level of transdisciplinarity and flexibility, and a relatively low level of diversity and integration. By late-2020, reflecting developments in the CESI work programme, these had shifted to a relatively high level of transdisciplinarity and medium level of diversity, flexibility, and integratedness. It should be noted that these assessments are provisional because they apply to an evolving, incomplete research programme.



**Figure 1: Provisional assessment of CESI’s interdisciplinary research status**

(T=transdisciplinarity; D=diversity; F=flexibility; I=integratedness)

**Transdisciplinarity**

CESI places a strong emphasis on involving business and local stakeholders. This reflects the Centre’s strong relationships with the business sector (a distinctive feature of the CESI research proposal), and a developing emphasis on local demonstration and pilot projects in the CESI research programme. However, there were some suggestions that CESI is less well connected to some stakeholders (such as national policymakers) and also that the Centre’s advisory groups could include more diverse stakeholder perspectives. The work of CESI’s advisory bodies could also be disseminated more fully across the consortium.

**Diversity**

CESI was established with a relatively low level of disciplinary diversity compared to some other WES initiatives in the UK. In early 2019, over three quarters of the CESI consortium had a broadly engineering or physical sciences disciplinary background. This is consistent with an understanding of ESI as a particular form of WES research, oriented to engineering and physical sciences. There has since been a broadening of the disciplinary base, with early rounds of the Flex Fund used to encourage this. At the same time, encouraging greater disciplinary diversity will present additional challenges for research integration.

**Integration**

As has also been seen in other similar centres, CESI has faced challenges in establishing Centre-wide integrative working. Despite some successful initiatives at project and workshop scales, establishing integrative working within and across workpackages has taken longer than anticipated; varied levels of workpackage efforts at integration, geographic dispersion and thinly spread resources with short term contracts for some research staff have all contributed to these challenges. CESI has taken steps to promote more integrated working across the centre, including directing later round Flex Funds to integrative research driven by existing consortium members.

**Flexibility**

Funding in CESI core and flex activities are spread thinly, and like other similar centres, limited resourcing means the Centre has faced a trade-off between openness and integration. At the time of our project fieldwork in 2019, CESI had commissioned one round of Flex Fund projects, and the emphasis in Round 1 was on bringing in new research teams and disciplines. Later Flex Fund rounds have placed greater emphasis on existing members of the CESI consortia and strengthening research integration. However, CESI Flex Fund projects are relatively small and short term, raising additional challenges for the coherence and integratedness of the research programme.

**References**

Frodeman, R. J. Thompson Klein, C. Mitcham (Eds.), The Oxford Handbook of Interdisciplinarity, Oxford University Press, Oxford, 2010,

Silvast, A., Hannon M. and Winskel, M (2019) Interdisciplinary Whole Systems and Systems Integration Research: A literature review, April 2019 (CESI Flex Fund project document)

McDowall, W. (2014). Exploring possible transition pathways for hydrogen energy: a hybrid approach using socio-technical scenarios and energy system modelling. Futures, 63, 1-14.

Winskel, M. (2018) ‘The pursuit of interdisciplinary whole systems energy research: Insights from the UK Energy Research Centre’, Energy Research and Social Science, 37, 74–84

# Introduction

## Project Introduction and Aims

This is the final report on the National Centre for Energy System Integration (CESI) Flex Fund Project *Interdisciplinary research for energy systems integration:**understanding and promoting good practice* (FFC1-022). The project has developed original insight on the practice and outcomes of energy systems integration research. It also sought to support improvements in research practice and outcomes, both within CESI and the broader whole energy systems research community in the UK.

The project addressed three research questions

1. How can different academic disciplines (and academic and non-academic stakeholders) be effectively combined for energy systems integration research?
2. What are the relative strengths and weaknesses of different inter-disciplinary research designs?
3. What good practice guidelines for interdisciplinary energy systems integration research emerge from analysis of UK and international experience?

## Project schedule and delivery

The project was commissioned as part of the first round of CESI’s Flex Fund, in 2018. It was led by Dr Mark Winskel and also involved Dr Matthew Hannon and Ragne Low, University of Strathclyde and Dr. Antti Silvast (University of Durham). Although scheduled to run from January to June 2019, the delivery of the workprogramme was delayed by staff changes and other factors.[[2]](#footnote-2) With the support of CESI senior staff and contract managers the project received a series of no-cost extensions to allow the work programme to be completed, and the interim results were presented at a number of CESI research and stakeholder events.

## Research Methods and Tasks

The project was designed around a small number of tasks and outputs, using mostly qualitative research methods:

* A desk-based systematic **literature review** of energy systems integration (ESI) research design and methods, including peer-review journal papers and grey literature. The review analysed the origins of ESI research initiatives, the opportunities and challenges involved and the perceived impact and value of such research. Findings from the literature review are summarised in Section 2 of this report.
* Researcher and stakeholder **workshops**. Three workshops were convened over project lifetime; each had a particular aim within the overall project design:
	+ The first workshop (n = 13) was convened soon after the project start, as an internal CESI-only event. The aim was to raise awareness within CESI about the aims of our research, and then discuss the experiences of, and views on, interdisciplinary energy systems research within and beyond CESI. The first workshop was hosted by CESI at the University of Newcastle. A summary of Workshop 1 findings is provided in Section 3.1 of this report.
	+ The second workshop (n = 25) involved researchers drawn from both CESI and the wider UK interdisciplinary energy research community. The aim was to compare experiences of similar interdisciplinary whole systems research initiatives. The second workshop was held at the Edinburgh Centre for Carbon Innovation (ECCI) at the University of Edinburgh, and was co-hosted by ClimateXChange, Scotland’s national centre of expertise on climate change. The workshop is introduced in more detail in Section 3.2 of this report, and selected insights are included in Section 5.
	+ The third and final workshop (n=c.50) engaged more widely with energy research users, stakeholders and researchers. The aim was to address user (or stakeholder) needs related to energy systems integration research in the UK, while also reporting our preliminary research findings. The third workshop was held at the Technology and Innovation Centre (TIC) at the University of Strathclyde, and was co-hosted by the Energy Technology Partnership (ETP) and the Energy Systems Catapult. The workshop is introduced in more detail in Section 3.3. of this report.
* Semi-structured **interviews** with senior researchers and stakeholders involved in interdisciplinary energy systems research in the UK. The interviews provided insights on the detailed experiences and views of those involved in developing and using interdisciplinary research on energy systems in the UK, addressing the achievements and perceived strengths and weaknesses of different research designs and practices. The interviews are introduced in more detail in Section 4 of this report, and the findings from the interviews are presented in Section 5.

## Summary of Research Outputs, to date

**Internal Documents**

* Antti Silvast, Matt Hannon & Mark Winskel, Interdisciplinary Whole Systems and Systems Integration Research: A literature review, April 2019 (internal document)
* Antti Silvast and Alison Norton ‘Coded transcript of the CESI interdisciplinary research workshop on 28th February, 2019’ June 2019 (internal document)
* Michael Kattirtzi ‘Notes on the CESI Flexi Fund Interview Transcripts’, June 2019 (internal document)
* Mike Kattirtzi, Alison Norton and Mark Winskel ‘Interdisciplinary research for energy systems integration: understanding and promoting good practice: Notes on the Edinburgh workshop on Monday 24th June’ October 2019 (internal document)
* Michael Kattirtzi, ‘Analysis of CESI interviews, workshops and seminar discussions’, October 2019 (internal document)
* Matthew Hannon, Oluwafisayo Alabi and Mark Winskel ‘Interdisciplinary research for energy systems integration: Identifying the Needs for Users’ Notes on the Glasgow workshop on 31st January 2020 (internal draft document)

**Public Documents**

* Mark Winskel (with Matthew Hannon and Antti Silvast) ‘Interdisciplinary Research for Energy Systems Integration: Understanding and Promoting Good Practice’, presentation to CESI Industrial Innovation Board, Newcastle, 30th April 2019.
* Mark Winskel (with Michael Kattirtzi and Matthew Hannon) ‘Interdisciplinary Research for Energy Systems Integration: Understanding and Promoting Good Practice’ presentation to CESI Research Conference 2019, Newcastle, 23rd July 2019.
* Mark Winskel ‘Doing Energy Systems Integration Research’ presentation to the ‘Interdisciplinary research for energy systems integration: Identifying the Needs for Users’ Glasgow workshop on 31st January 2020.
* Antti Silvast ‘Energy Futures: Understanding Integrated Energy Systems Modelling’. Book chapter for the forthcoming *Research Handbook on Energy and Society* F. Wade, J. Webb and M. Tingey (eds). Edward Elgar, 2021.

# Literature Review

The literature review (Silvast et al., 2019) used a systematic evidence review protocol to analyse academic peer-reviewed research and grey literature on Energy Systems Integration (ESI). The review covered – in varying levels of detail according to the available literature – the origins and intended aims of ESI research, different ESI initiatives seen internationally, the research methods used, the perceived impact of such research, and any reported challenges.

The literature review traced the modern origins of ESI to an international research initiative in the early 2010s involving University College Dublin, Colorado State University and the National Renewable Energy Laboratory (NREL) in the United States.

The review also considered two related concepts in interdisciplinary energy research: 'whole energy systems' (WES) research and ‘energy systems integration’ (ESI) research. This drew on the 3-fold characterisation of WES research devised by Winskel (2018):

* *intellectual diversity*: WES research initiatives typically include diverse academic disciplines, involving different data, methods, and forms of evidence. Working across these diverse knowledge bases is a defining challenge for WES interdisciplinary initiatives.
* *integration*: unlike some other forms of interdisciplinary research, WES research initiatives typically aim at integrating the work of academics from different disciplines to develop common research designs and research outputs.
* *transdisciplinarity:* WES research initiatives may have a strong level of engagement with non-academic stakeholders, including businesses, policy makers and wider publics. For more ‘transdisciplinary’ oriented research initiatives, non-academic stakeholders are viewed as active research collaborators, co-designers and co-producers, rather than passive research users.

Appendix 1 offers an interim assessment of CESI as an ESI / WES research initiative using these three criteria, and an additional ‘flexibility’ criterion reflecting the extent reflecting the choice in WES programme design between fixed funding and membership, versus more flexible arrangements.

The review went on to consider WES and ESI as distinctive research concepts; it concluded that they differ in terms of their analytical scope and focus: while WES research initiatives typically aim to analyse energy systems and system change in relatively broad terms, spanning relations between technology, society, the economy and the environment, ESI research initiatives have typically been more concerned with analysing detailed interactions and interdependencies of energy system vectors and infrastructures. As such, ESI research to date could be characterised as a particular form of whole energy systems research, with distinctive characteristics:

* *Limited (or bounded) intellectual heterogeneity:* while ESI research initiatives (like broader WES initiatives) draw on multiple disciplinary perspectives and methods, ESI research consortia tend to be primarily oriented around engineering and physical science and economic research perspectives and methods, with a less central role for non-economic social sciences and environmental sciences.
* *Engineering-based knowledge production:* reflecting its distinctive intellectual make-up, interdisciplinary knowledge production in ESI occurs most commonly between different engineering and physical sciences and economics, such as between power systems engineering and other physical science disciplines such as computer science, computer simulation and mathematics. This is a relatively ‘proximate’ form of interdisciplinarity, rather than the more ‘radical’ forms spanning the social, engineering and environmental sciences, which characterises some WES research initiatives.
* *Linear knowledge transfer:* non-academic stakeholders such as policy makers, business representatives and consumers, have been involved in several ESI projects internationally. However, rather than active co-designers of research outputs and designs, stakeholders often featured as anticipated research users. ESI initiatives to date have tended toward a relatively limited form of transdisciplinary relations, based on linear knowledge flows between researchers and users.

The review also considered the suggested benefits and challenges of adopting an ESI research approach. These have included: increased energy system efficiency, enabling the greater use of renewable energy technologies in energy systems and improving energy system security and flexibility. Among the recognised research challenges in the literature was a weak representation of ‘real-world’ energy system integration processes, including institutions, organisations and markets. Some authors have suggested that involving a wider array of disciplines, and working within a broader definition of whole systems, would help address this issue.

The review also concluded that the ESI research initiatives have shown limited reflexivity to date, in terms of paying explicit attention to interdisciplinary research designs and methods and developing explicit responses to the challenges involved. Even when these issues were recognised, they tended to be addressed in the context of specific integrative methodologies, particularly computer modelling, rather than wider aspects of research design and practice, or by drawing on insights from the wider interdisciplinary studies research literature.

Finally, the review found limited cross-referencing between different ESI research initiatives, and concluded that greater recognition of the shared strategic and operational challenges facing different initiatives could support innovative research designs and methods. Without this, there may be repeated missed opportunities for community-level learning within the international ESI research.

# Project Workshops

**3.1 Workshop 1: Facilitated Group Discussion**

### Introduction

While the literature review considered international ESI initiatives, the first project workshop focussed on the experiences and views of members of the CESI consortium itself. The workshop was convened as a facilitated group discussion in February 2019 at the University of Newcastle, the home of CESI’s PI and management team.

All members of the CESI research consortium (as of January 2019) were invited to the meeting. Although it was attended by a relatively small proportion of the consortium (13 people including 3 members of the interdisciplinary flex fund project), participants spanned a wide range of roles, disciplines and levels of seniority within CESI. The meeting was held under the Chatham House rule, and participants were assured of anonymity in reporting the findings.

The meeting was conducted as a semi-structured discussion, led by Dr Winskel and Dr Hannon, across three main themes:

* *Motivations:*
	+ the external drivers for WES and ESI interdisciplinary research, in CESI and more generally
	+ individual, personal reasons for engaging with other research disciplines
	+ the main barriers facing whole systems interdisciplinary research, in CESI and more generally
	+ whether ESI research requires particular forms of interdisciplinary working, in terms of participating disciplines, research designs and outputs
* *Experiences:*
	+ how well CESI is working as an interdisciplinary research centre?
	+ which areas or activities have been most successful in CESI (e.g. research projects, workpackages, demonstrations, Centre-wide activities or stakeholder engagement activities)? Which areas have been less successful?
	+ how does CESI compare to other whole systems interdisciplinary research programmes, in your experience?
* *Recommendations:*
	+ suggestions for improved ways of interdisciplinary working (within CESI and more generally) in terms of:
		- research methods, designs and outputs
		- management and co-ordination processes
		- relationships with funders, advisors, business partners, reviewers, the wider research community, etc.

The meeting was audio recorded, fully transcribed, and then coded by Dr Silvast, according to the above themes and more detailed issues raised in the course of the discussion. The main findings are summarised below. In reporting the findings, it should be noted that the workshop took place at around mid-way through the CESI research programme, and that the experiences and views reported below do not reflect later experiences and views of CESI members.

### Motivations for ESI Research

In terms of external motivations for ESI research, workshop participants suggested that the scale of envisaged energy systems change required the participation of wide-ranging academic disciplines to produce economically and socially useful research. ESI initiatives such as CESI offer an opportunity to researchers to work across different energy vectors and sectors – while at the same time overcoming academic specialisms and knowledge silos. A number of more specific external drivers for ESI were also mentioned:

* the emergence of disruptive technologies which cut across energy services (power, heat and transport), such as electric vehicles and heat pumps
* increasing interactions between two big energy 'vectors' in the UK, gas and electricity (e.g. gas to power, and power to gas)
* the particular challenge of decarbonise heat, which is happening much slower than decarbonising power
* ‘policy failure’: especially, the failure to meet carbon targets and the need for improved efforts on energy demand reduction and efficiency to meet climate change targets

For engineering and physical scientists, ESI research initiatives also offer an opportunity to engage with the public, develop improved public understanding, and better engage with technology end users. This means drawing on diverse areas of the social sciences relating to households, businesses and governance. Increasing commercialisation pressures in the energy system increase the importance of public / user acceptance – and therefore the relevance of social science academic disciplines.

Some researchers also cited a personal motivation for their involvement in ESI research. Interdisciplinarity allows researchers to learn from other academic disciplines (their different ‘languages’, approaches and methods), and this can lead to unexpected research benefits. One workshop participant gave the example of unanticipated synergies between engineering and anthropology. This suggests that the value of interdisciplinary collaborations can’t always be predicted, and space should be allowed in research designs for explorative research.

More instrumentally, it was also recognised that interdisciplinarity in CESI and elsewhere arises from the requirements of funders and assessors, and in particular, the need to secure good proposal reviews.

In terms of the scope and design of ESI research, it was noted that interdisciplinary work between different engineering disciplines, e.g. between mechanical engineers and civil engineers – what is sometimes termed proximate interdisciplinarity – can be more challenging and create greater tensions than more ‘radical’ forms across the physical and social sciences.

There was also some acknowledgement of the distinctiveness of ESI research compared to WES research. Here, it was argued that compared to WES, ESI has a greater emphasis on cross-sector integration. One participant drew a clear distinction between more focussed multi-vector network projects based in the engineering and physical sciences – such as the EPSRC’s Energy Networks Hub – and broader whole systems energy research.

### Experiences of ESI research within the CESI research consortium

A number of workshop participants noted that interdisciplinary working in CESI – especially Centre-wide integrative research – had taken longer to develop than first thought. For example, CESI’s ‘co-evolution cycle’ framework has not been as easy or straightforward to implement as anticipated. The challenges mentioned here included developing and consolidating links between different workpackages, different universities and different individual researchers.

CESI involves around 150 people, including flex projects, and 25 Co-Is. These are geographically distributed, making day-to-day conversations difficult – many academics have tended to prefer small group face-to face discussions. For CESI managers, this also means that researchers’ identification with the ‘CESI brand’ is difficult to maintain, especially for more dispersed members of the consortium.

Given the challenges of Centre-wide integration, the early focus in CESI shifted to smaller scale activities: encouraging researchers to collaborate on specific tasks, for example: ‘task and finish’ subgroups. Although these helped progress research, these subgroups tended to introduce new silos and integration challenges – for example, between different kinds of models (the CESI consortium includes at least seven different models and multiple associated scenarios).

One particular initiative was the setting up of ‘bootcamps’ to bring researchers (especially junior researchers) together to consider research issues not specific to work package tasks. One bootcamp on ‘uncertainty’ prompted cross-disciplinary exchanges on what to consider when building models, while another enabled the participation of an internationally-recognised expert on research impact. The bootcamps received good feedback and are regarded as a useful means of interdisciplinary working by CESI’s programme managers.

The CESI annual research conference is another initiative which supports integration across the Centre’s activities, and also builds links with the wider energy research community.

The challenges of Centre-wide integration also prompted the creation of CESI ‘leadership meetings’. However, CESI managers found it difficult in practice to convene leadership meetings which gathered together senior Co-Is in the same room. All participation in CESI is done on a voluntary basis, and although participation of Co-Is leadership meetings is encouraged, leadership of integrative research across CESI’s different workpackages has been inconsistent.

### Stakeholder and policy engagement activities

CESI has two formal advisory bodies: an Industrial Advisory Board (IAB) and an International Scientific Advisory Board (ISAB). These bodies have different roles and interests: the IAB tends to focus on business opportunities and partnerships, and ISAB on research developments. While CESI’s industrial stakeholders have rather specific engagements with CESI, international academics face interdisciplinary challenges in their own organisations and countries, and can offer useful advice on broader whole energy system aspects.

One participant noted a challenge for energy researchers stemming from the greater number of stakeholders involved in the contemporary energy system, compared to the a relatively small number of people involved in the past.

While some participants in the group discussion saw CESI as having a distinctive emphasis on working with non-academics, it was also noted that CESI has limited resources for stakeholder and policy engagement, such as responding to government consultations. In terms of its general approach to policy engagement, CESI focuses on more strategic, commercial and pragmatic aspects of system integration, rather than more overtly political aspects. CESI tends to engage in energy policy, governance, and strategy in terms of ‘decision-making’ – for example, how decision makers and system architects at different scales have different knowledge needs, reflecting their different ‘risk perspectives’

### Early use of flex funds

Like several other large UK based interdisciplinary centres, CESI has some of its research funds allocated to a ‘Flex Fund’, which commissions projects over a series of open calls over the lifetime of the Centre. The flex fund was established at the request of funders, with CESI allowed to administer it. CESI managers decided that early flex funds should be used to bring new partners into the consortium, and proposals involving new partners were favoured in reviewing first round of Flex Fund; introducing new researchers was seen as strengthening the consortium at this early stage.

### Recommendations for improved interdisciplinary energy research

Workshop participants offered a series of suggestions for improved interdisciplinary ESI research:

* Interdisciplinary aspects need greater consideration at the proposal development stage; any next-phase CESI bid should be developed in a structured and integrated way, with consideration for different disciplinary terminologies and languages, and how modelling assumptions, inputs and outputs can be made more transparent.
* There is value in encouraging informal discussions with people in other disciplines; some of the more useful CESI meetings have focused on rather general conceptual issues, such as the role of modelling.
* There is a problem in publishing interdisciplinary research in disciplinary journals. In CESI, for example, a buildings statistics paper was seen as inappropriate for a statistics journal, but also outside the remit of a buildings engineering journal.
* Flex funds are a useful means of overcoming a ‘closed shop’ consortium and increasing research community engagement, but in CESI the Flex Fund projects are only weakly connected to the Centre as a whole: they should be required to report their findings across the Centre. CESI working papers could be collated to offer a joint, Centre-wide repository of information, informing subsequent research.
* Policy makers tend to use particular models and ignore others, presenting a barrier to novel interdisciplinary research. CESI and other initiatives should improve their channels of influence and advice with government on the use of unfamiliar research.
* The employment of RAs on short-term contracts encourages project specific disciplinary working and discourages Centre-wide interdisciplinary working. Rather than multiple short RA positions, it would be better to focus researcher funds over a longer time period, such as a PhD studentship or post-doctoral fellowship.
* Academic and stakeholder developments should better have brought together in CESI – including the work non-academic bodies, such as local energy strategies being developed by local authorities.
* Proposal review remains a barrier, and interdisciplinary proposals are often evaluated by monodisciplinary experts.

**3.2 Workshop 2: Researcher Perspectives on Energy System Integration Research**

The second workshop brought together 23 interdisciplinary researchers and analysts drawn from the UK energy research community (a list of participants is given in Appendix 1). The aim was to consider the experiences and insights of a number of similar WES and ESI research initiatives, in terms of interdisciplinary research strategy and practice. The workshop was held on 24th June 2019 at the Edinburgh Centre for Carbon Innovation (ECCI) at the University of Edinburgh, and was co-hosted by ClimateXChange, Scotland’s national centre of expertise on climate change.

The agenda for the meeting was developed around three generic challenges facing interdisciplinary WES research initiatives:

*Theme 1: Managing Disciplinary Diversity*

* The Transition Pathways approach, Professor Geoff Hammond (University of Bath) and Professor Peter Pearson (Imperial College)
* The UKERC Phase 1 and Phase 2 approaches, Dr Mark Winskel (University of Edinburgh and UKERC)

*Theme 2: Integrative Methods and Outputs*

* The Energy System Catapult’s Clockwork and Patchwork scenarios approach, Scott Milne, Head of Insights, Energy Systems Catapult
* Combining bottom-up analysis with systems modelling, Dr Charlie Wilson, University of East Anglia and IIASA
* The CESI approach, Professor Phil Taylor and Dr Sara Walker (University of Newcastle and CESI)
* The EnergyREV approach, Dr Rebecca Ford (University of Strathclyde and Energy REV)

*Theme 3: Providing decision support for policy and strategy*

* Whole systems analysis for decision support: a personal view, Alec Waterhouse (Head of Modelling, BEIS)
* A view from the Scottish Government, Ragne Low (Scottish Government)
* Managing uncertainty in modelling – good decisions for the real world, Dr Chris Dent (University of Edinburgh and CESI)

Slides from the presentations are available from the project webpage on the CESI website. Some contributions and insights from the workshop are incorporated into Section 5, ‘Results’, below.

**3.3 Workshop 3: Stakeholder Perspectives on Energy System Integration Research**

The focus of the third workshop was understanding energy systems integration research from users’ perspectives. The workshop was held at the Technology and Innovation Centre (TIC) at the University of Strathclyde, and was co-hosted by the Energy Technology Partnership (ETP) and the Energy Systems Catapult; around 50 people attended the workshop (see Appendix 2 for a list of registrees).

The agenda was structured around perspectives on ESI research from a number of different organisations (representing different user groups), followed by small group discussions. The workshop began with a presentation of the project’s preliminary overall research findings.

*Interim findings from the CESI Interdisciplinary Project*

* Doing Energy Systems Integration Research: Findings from the CESI Flex Fund Project, Dr Mark Winskel, University of Edinburgh (presentation slides are available from the project webpage on the CESI webpage)

*Panel 1: User Priorities for Interdisciplinary Energy Systems Integration Research: Cross-sector Perspectives* (Chair: Professor Karen Turner, University of Strathclyde)

* An Energy System Catapult perspective, Eric Brown, Chief Technical Officer
* A Scottish Government perspective, Simon Gill, Head of Whole System and Technical Policy Directorate of Energy and Climate Change
* An NGO perspective from Zero Waste Scotland, Paul Gilbert, Project Manager, Low Carbon Heat and Renewables
* An academic perspective, Dr Jonathan Radcliffe, Reader in Energy Systems and Policy, University of Birmingham

*Panel 2: Designing Interdisciplinary Energy Systems Research Integration: Intermediaries’ Perspectives* (Chair: Dr Matthew Hannon, University of Strathclyde)

* An Energy Technology Partnership perspective, Professor Karen Turner, ETP Energy, Policy, People & Society Theme Coordinator
* A CESI perspective, Professor Phil Taylor, Centre Director
* A UKRI perspective, Derek Craig, Head of Regional Engagement (Scotland), Engineering and Physical Sciences Research Council (EPSRC)
* Scottish Enterprise perspective, Jan Reid, Senior Manager, Low Carbon, Scottish Enterprise

Some contributions and insights from the workshop are incorporated into Section 5, ‘Results’, below.

# Interviews

The project interviews were used to generate mostly a ‘beyond CESI’ view on WES and ESI research in the UK, including suggestions for improved research strategy and practice. Thirteen semi-structured interviews were conducted by Dr Winskel and Dr Silvast between April and June 2019, involving nine senior researchers with extensive experience of WES research and four senior stakeholders experienced in advising and supporting and WES research initiatives in the UK. A follow up interview was conducted by Dr Winskel with two CESI senior staff in January 2020.

The interviews were structured around a set of questions sent to the interviewees in advance. The issues covered were similar to those covered in the facilitated group discussion:

* Background
	+ professional background of interviewee
	+ definitions and understandings of WES and ESI research, in terms of:
		- intended research contribution and impact
		- research design and methods
		- relevant contributing research disciplines
		- the role of non-academic stakeholders
* Experiences of working on WES and ESI research initiatives, including the strengths and weaknesses of different initiatives
* Recommendations and suggestions for improved ways to conduct WES and ESI research

The interviews lasted between 50 and 90 minutes. The interviews were audio recorded, fully transcribed and then coded and analysed by Dr Kattirtzi. The interviewees had varying levels of familiarity with CESI, and the discussions tended to address WES and ESI research issues more generally, although some CESI-specific observations were also made in some cases. The themes emerging from the interviews are summarised in the next section, illustrated with selective quotations.

# Findings from interviews and workshops

Although this section mostly draws on a formal analysis of the interview transcripts, it also includes a small number of contributions made at the project workshops. The results are presented as a series of themed observations and recommendations, illustrated with quotations from fieldwork participants.

## Defining and demarcating WES and ESI research

Several fieldwork participants drew a distinction between Energy System Integration (ESI) research and Whole Energy Systems (WES) research, in terms of their research aims and disciplinary orientations. Typically, ESI was seen as a more technical research framing, oriented towards engineering and aimed at understanding how different technical parts of the energy system could be integrated, without necessarily considering broader issues. WES research was seen as offering a broader interdisciplinary view, perhaps with a greater emphasis on social science than seen in ESI research:

*‘Energy systems integration is about seeing the different bits of the energy system being integrated better, so taking advantage of energy storage, flexibility … it has that sort of technical flavour to it.’*

Professor in mechanical engineering

*‘A whole energy systems view might include broader concerns around kind of political trends and cultural embedding of technologies … which perhaps don’t feature in energy systems integration research’*

Senior interdisciplinary energy system researcher

*‘[Whole Energy Systems] research incorporates the interests of society, social justice, democratic practice … I would put it very much in terms of societal aims and objectives.’*

Senior academic social scientist

Asked to describe the relationship between the two, a number of interviewees suggested that ESI research should be seen as a subset of WES research:

*‘Energy systems integration effectively is a subset of whole energy systems … integrating different parts of either systems or different vectors, or looking at … regional or local … energy systems.’*

A senior manager in a UK Government research funding body

*Energy systems integration research is a subset of a broader whole energy systems research agenda.’*

Senior interdisciplinary energy system researcher

*‘Energy systems integration research … [is] a subset of energy research … there are aspects … like electric vehicle charging … where there’s purely technical research to be done.’*

A Professor in Energy Policy

There were also suggested complementarities between the two, with ESI seen as analysing detailed system interactions, while WES research provided a broader, contextual framing:

*‘The two things [WES and ESI research] … should go hand-in-hand, and there should be a lot of learning between the two.’*

A senior manager in a UK Government research funding body

*‘You’ve got to do those deep dives … and you need to keep coming back up from the deep dive and meeting up with other people … making sure that … there’s an ongoing … integrated approach.’*

An energy research and policy advisor with industry experience

One interviewee expressed a concern about the risk of disconnects between more focussed ESI research and broader WES research:

*‘We do have to think about how [WES and ESI] work together. You can have unintended consequences, if …you’re optimising one bit and you realise that if you’d thought about two bits together, you would have come up with a more optimal solution.’*

A Professor in Electrical Engineering

## Research Designs and Methods

### The role of modelling

In terms of WES and ESI research designs and methods, several participants discussed the role of modelling. For many, modelling is an essential feature in interdisciplinary research on energy systems because it enables integrated analysis of a complex system, and helps identify key research or strategy issues:

*‘Inevitably, at different … scales, you’re using different models, because things just become not just computationally intractable but intractable in terms of understanding … models [are] a means of improving understanding.’*

A Professor in Electrical Engineering

 *‘[In our project] we had something like … eight or nine different models… for modelling different bits of the transition pathway, but … it seemed to work.’*

A Professor in Mechanical Engineering

 *‘When [our] strategy team… got established … the modelling … [helped us] understand which solutions… we need to be working on.’*

A former senior manager in an energy research organisation

At the same time, there was recognition that models – and particularly the use of several different models in an interdisciplinary research consortium such as CESI – can obscure understanding and create barriers to integrative analyses. One concern was that energy system modelling tends to reflect engineering and economic analysis, and marginalise other disciplinary perspectives; for one interviewee, this concern led to an interest in alternative forms of modelling:

 *‘Futures and scenarios studies … in the energy sector … have been quite narrow … mainly from an engineering or … technocratic … perspective.’*

An early career social scientist in CESI

 *‘Whole energy systems work … has traditionally been techno-economic type models, big optimisation models that have been heavily used both for research as well as for policy … I have … moved from doing techno-economic modelling to … social governance modelling, whilst still trying to have a whole systems perspective.’*

A professor in energy system modelling

Finally, one participant argued that whole energy system modelling and scenario analysis was becoming less important as the energy research and policy shifted away from pathway development towards implementation; this meant that the key issue was to ensure **feedbacks** between system modelling and ‘real world’ data from implementation trials:

*‘The UK’s almost been modelled to death … We’ve reached the point where … we don’t need more academic research until we’re actually delivering some of this stuff … then we need the learnings from delivery built back into academia.*

A modelling expert in industry

### Research scope and disciplinary range

Some participants were concerned that the technical and engineering emphasis in ESI research may lead to a narrow research scope, possibly overlooking important social, behavioural and political aspects of change affecting, for example, personal transport, or rescaled power systems. The implication here was that addressing these societal issues required a wider disciplinary range than may be seen in ESI research:

*‘My fear would be that the energy systems integration approach just takes where we are today and says, how do we adapt what we’ve got today … We finish up locked into pathways which don’t provide … radical change … Where are the … people who are saying, ‘hang on, will cars be there in 2050 in the way that we have them today?’ … My fear is that [ESI] will just take an assumption that we’ll still have 30 million cars on the road, and there’ll just be electric vehicles with batteries in.’*

A former senior manager in an energy research organisation

 *‘Sometimes you have to take an extreme view to … force the boundaries of thinking… As an engineer, you can dismiss that and go … ‘it’ll never happen’, ‘it won’t work’ … … [but] if that’s the world that people desire, then … tweaking the … centralised engineering view of the world … just isn’t enough’.*

A modelling expert in industry

*‘The solutions that work for society as a whole don’t necessarily optimise the energy system, or they optimise it in a different way which isn’t just about delivering low carbon at lowest cost … We could head in that direction in the whole systems space.’*

A former senior manager in an energy research organisation

### Research integration methods

There was some discussion of how best to combine qualitative and quantitative research into a ‘mixed methods’ overall design. One senior engineer stressed that quantification was critical to delivering impactful research:

*‘If you can’t persuade a policy maker how much something is going cost, they’re not going sign on to that policy, regardless of how many warm words you come up with.’*

A Professor in electrical engineering

By contrast, another interviewee argued that an emphasis on quantification can lead to research biases and omissions – and stressed the need for a mixed methods approach:

*‘Scenarios are important and useful when they open up conversations that… help clarify the kind of knowledge claims that can be made by models … If we always only put into scenarios what we can quantitatively describe … with our models … we … put into the background things that we know to be very important.’*

A senior interdisciplinary energy system researcher

Although research integration is a defining feature of much ESI and WES research, one interviewee was critical of research designs which sought to integrate diverse disciplinary perspectives, and called for a less integrated approach to interdisciplinary research:

*‘I would much prefer to have the disciplines using approaches which are appropriate to their discipline, and then think … about how that can be brought together and what that says about the whole … transition’.*

A professor in energy policy

As an example of a less integrated approach, the interviewee highlighted a project which analysed household battery storage using a combination of stakeholder workshops and business model analysis to offer a multidisciplinary – but not tightly integrated – range of evidence to decisionmakers.

### Novelty and consolidation

One challenge for developing integrative designs is that funding and publication systems tend to favour novelty: for example, building new models, rather than integration, consolidation and verification: for example, improving links between existing models, updating or archiving data or reviewing past findings:

*‘Working to help somebody else improve the quality of the data in their model, or make sure that models … or researchers interact with each other just isn’t rewarded.’*

A modelling expert in industry

*‘We’ve developed academic … processes to make incredibly strong academics, but … we haven’t created a process that rewards integration.’*

A modelling expert in industry

Some highlighted data curation issues, and the significant extra workload associated with developing and maintaining accessible data repositories – although it was also pointed out that some energy research consortia, such as Transitions Pathways and WholeSEM, had made deliberate efforts to improve multi-model linkages as part of their research design. Perhaps recognising that it is a distinct task, the Energy Technologies Institute (ETI) made sector experts, rather than modellers, responsible for data curation.

### Research outputs

Some participants noted that successful interdisciplinary research designs require a tangible task or output:

*‘Another useful lesson we had … was it’s quite important to give [researchers] a specific task and let them run with it.’*

A Professor in mechanical engineering

*‘In UKERC … we used the MARKAL model and everyone pitched in and we wrote a book about it and that was imperfect but it worked … you need something tangible for the consortium to come [together] around.’*

A Professor with expertise in energy system modelling

## Interdisciplinarity in practice

Alongside more formal aspects of research strategy, interviewees and workshop participants also discussed the more practical challenges of interdisciplinary collaborations, and offered suggestions for improved practice based on their own experiences. Many of this issues raised here reflect experiences of interdisciplinary research in general, rather than ESI or WES research specifically.

### Persistent institutional barriers

Some participants noted the persistent institutional and professional barriers to publishing interdisciplinary research:

*‘You can’t easily get work published that’s taking that interdisciplinary perspective … focus[ing] very narrowly in a disciplinary sense … gives you profile for your career.’*

A senior academic social scientist

*‘One thing I have experienced is … disciplinary publication …pressure … within our line management and schools.’*

A CESI interdisciplinary researcher

Some also argued that research commissioning and assessment procedures remain hostile to interdisciplinary research:

*‘This continues to be a challenge. I still don’t think funders understand whole systems … [and] the people who review the proposals do not … You still have … people saying … ‘why is this important?’ … ‘why are you linking all this stuff together?’’*

A Professor in energy systems with experience in modelling

*‘If it just goes back to a disciplinary panel, then you might as well not bother putting in your proposal.’*

A Professor in energy policy

*‘All of us involved in interdisciplinary research in the UK have felt the weight of disciplinary conventions when we’re going through research funding processes.’*

A senior interdisciplinary energy system researcher

### The extra time and effort involved

One participant noted that interdisciplinary research may not be considered high quality within disciplinary communities, despite the widely-shared view that serious engagement in interdisciplinary research requires more time and effort than monodisciplinary-based research:

*‘Interdisciplinary research … often involves people having to take at least one step backward before they can go forward. They have to work out what the other people are talking about … what their assumptions are, what sort of research questions they think are interesting. Until you do that, it’s quite hard to work together.’*

A Professor in energy policy

*‘It just took time for everybody with very, very different disciplines and approaches to come together effectively.’*

A Professor in economics

*‘We had to have a series of … internal … overnight meetings, to really get people to work together … We had a Rosetta Stone type process … [to] translate from engineering to economics to social science’.’*

A Professor in energy system modelling

The same Professor added that allowing time for interdisciplinary relationships to develop was key:

*‘It’s always better to have 1 million for 5 years than 5 million for 1 year … it’s the time element you particularly need.’*

A Professor in energy system modelling

The ‘extra time and effort’ issue was also mentioned as a challenge faced within CESI:

*‘Developing links between the work packages … universities … [and] individuals … has taken longer than expected … that has impacted on where we’ve got to.’*

A senior CESI researcher

Again drawing on CESI experience, the same participant noted that the time and effort demands of interdisciplinarity may not be acknowledged in research budgeting, especially for senior staff, where funding is often spread very thinly:

*‘if a lot of the academics are on 5% buy-outs, then you have one meeting a month and that’s the[ir] entire time … paid for.’*

A senior CESI researcher

### Early focus on collaboration

Other interviewees noted that it helps if the interdisciplinary research team builds on existing relationships:

*‘Successful collaborations … often arise from … pre-existing relationships.’*

A senior CESI academic researcher

*‘[The engineers] had all been part of the SuperGen project … that presented us with a problem because the social scientists didn’t have the same background.*

A Professor in mechanical engineering

Some participants highlighted the need for a focus on developing interdisciplinary relations at an early stage:

*‘Often planning of collaboration doesn’t happen at an early enough stage … really you want to have that in mind and have good relationships between people before the proposals even goes in.’*

A senior CESI academic

### Early career risks and opportunities

One senior research manager highlighted the particular risks for interdisciplinary early career researchers, given the professional and institutional barriers involved. Others argued that less experienced researchers were able to engage well in interdisciplinary collaborations precisely because they were less entrenched in disciplinary perspectives, and also because they were more likely to be able to devote the time and effort needed:

*‘For early career researchers, there are higher risks … [once] you’re already established … you can … put on hold the need for fundamental progress or original research in your own discipline to some extent.’*

A senior manager in a UK Government research funding body

 *‘It’s always easier to get … young people … to work together than … older principal and co-investigator people … Students will always work much better together.’*

A Professor in mechanical engineering

*‘It’s easier for more early career researchers to work together because you need so much time to do this … If you’re a full professor with 5 projects and X teaching staff … you just can’t understand someone else’s model or framework enough to work with them … Our successful joint [work] … was a bottom-up collaboration.’*

A Professor in energy system modelling

### The need for enthusiastic research leaders and facilitators

Another observation was on the importance of building an interdisciplinary research consortium around enthusiastic research leaders, researchers and facilitators:

*‘You … need … [a] discipline agnostic, omnipotent being to make that judgment as to actually what pieces of the jigsaw do you really need.’*

 A CESI interdisciplinary researcher

*‘I would rather have people who I could really get on with working on interdisciplinary research, even if they’re not the best people by some measure of publications or money rates’*

A Professor in energy system modelling

*‘There are people that sit at the centre of a number of different networks … [they’re] not necessarily the focal point … but they .... make the interdisciplinary network work.’*

A senior manager in a UK Government research funding body

### The role of social scientists

There was some discussion of the role of social scientists in WES and ESI interdisciplinary collaborations. For one academic engineer in CESI, social scientists are able to support technical research with public understanding or social acceptance; as another participant noted, this limited and essentially instrumental role is a familiar experience for many interdisciplinary social scientists:

*‘You can argue the technical case … [but] it’s completely pointless unless there is social acceptance of the project … people from various social science disciplines have expertise in engaging the public and understanding the issues that affect them … it’s very important to engage with this community.’*

An academic engineer in CESI

*‘For those of us who are at the social science end of interdisciplinary energy research, most of us will have had the experience of … being a kind of add-on who is there in order to … do some sort of ‘social voodoo’ to either make policy makers like what the models say or make the public like the technology … An expectation that the social scientists are there purely for instrumental purposes … for acceptance of whatever it is that the ‘real scientists’ come up with.’*

A senior interdisciplinary energy system researcher

While limited expectations mean that social scientists can be marginalised in some interdisciplinary collaborations, some observed that social scientists may be self-marginalising, because of their reluctance, in some cases, to engage with integrative research designs – preferring to focus instead on their own research issues. One interviewee noted that disciplinary diversity among behavioural and social sciences may present barriers to research integration:

*‘Psychological … [or] sociological … social scientists … [reflect] deep questions about … the way you think the world works … Social scientists tend to be more diverse and have less common ground than physical sciences’.*

A Professor in energy policy

### The role of non-academic stakeholders

Some participants argued that non-academic stakeholders had critical roles in WES and ESI research projects, in terms of asking challenging questions, and helping ensure that academic research has wider societal relevance and value (although this perhaps doesn’t amount to the deeper form of transdisciplinary research suggested by others):

*‘You’re more likely to ask and answer interesting questions if you get challenged from people who see the world in different way … Non-academic stakeholders … may not be able to offer much in terms of the actual research methodology but they can identify… interesting questions and give common-sense tests to outputs.’*

A Professor in energy policy

*‘Without non-academic stakeholders, you can’t define … [the] problems … that the energy system faces … that comes directly from my understanding of what whole energy systems research is for.*

A senior interdisciplinary energy system researcher

### The need for improved cross-centre learning

Finally, a number of participants noted that, in responding to the challenges of interdisciplinary WES and ESI research, there are untapped opportunities for different research centres to learn from each other’s experiences:

*‘There’s an awful lot of … new things and much less stock taking … that’s endemic in all kinds of organisational environments but it seems to be … escalating in energy … There’s a sense of urgency and money to be spent, but not a lot of reflectivity.’*

A senior academic social scientist

*‘I haven’t got any evidence to suggest that there’s been any kind of deliberate kind of learning, cross-consortium learning’*

A Professor with expertise in energy system modelling

One participant added that there were also challenges in drawing on research and demonstration findings in particular initiatives such as CESI for wider research community benefit:

*‘How can CESI leverage … [its] demonstration activity to be able to use that in its analysis and insights but also make sure that that is captured … for … ongoing research agendas?’*

A senior modelling expert in industry

# Good Practice Recommendations for ESI Research

## Recognise ESI research as a distinctive form of WES research

Energy Systems Integration (ESI) research is a distinctive form of WES research, with particular aims and intended contributions. To date, much ESI research internationally has tended to reflect a predominantly techno-economic and engineering-based disciplinary view of whole energy system change, although more recent ESI initiatives such as CESI have taken steps toward greater diversity in terms of disciplinary participation and research strategy.

Recognising ESI research as a distinctive form of WES research is important in fairly judging its research strategy and outputs – yet research for this project suggest that this distinction is poorly understood among researchers, stakeholders and funders. The relationship between ESI and WES research in the UK needs to be more clearly defined and articulated. There is also a need for greater clarity on the contribution of individual initiatives such as CESI in the UK’s overall WES research portfolio.

## Decide on interdisciplinary **ambition and participation**

While there is no single best practice blueprint for effective interdisciplinary research, it is useful for interdisciplinary research centres to be explicit about their interdisciplinary ambition, in terms of developing centre-wide integrated research output and the extent of co-design and/or co-production with non-academic stakeholders. Collaborations across disciplinary boundaries take time to nurture, and different levels of ambition imply different research designs, effort and time commitment from researchers and managers, and different resource needs. For example, centre-wide research integration requires a significant commitment of resources and leadership effort.

Perceived failings in interdisciplinary initiatives may relate to unrealistic expectations. It is useful to set out, early on, the nature and extent of interdisciplinary ambition, drawing on wide experiences, while also allowing some flexibility given that research programmes develop and change over time.

More explicit consideration should also be given to what is an appropriate disciplinary balance for CESI, in terms of its ability to deliver its research programme. Disciplinary make-up will condition the forms of whole systems interdisciplinary research that CESI can undertake. For example, as a form of whole systems interdisciplinary research oriented towards the engineering and physical science disciplines, it may be seen as less appropriate for ESI consortia to aim for an even balance of broad disciplinary representation than seen in some other WES initiatives in the UK.

## Draw on wider experiences and expertise

Devising, implementing and regularly reviewing interdisciplinary progress should be an explicit part of CESI’s overall research strategy. CESI’s International Scientific Advisory Board (ISAB) currently offers some guidance for interdisciplinarity in CESI, but consideration should be given to strengthening the advice and support from those with similar experiences of co-ordinating large interdisciplinary research programmes in the energy systems research community, and also more widely in the interdisciplinary studies research community.

## Recognise the trade-off between flexibility and integration

A strong emphasis on flexibility, openness and diversity in research centre strategy can erode capacity for more ambitious forms of interdisciplinarity which rely on close understanding, familiarity and trust. Research for this project and elsewhere (e.g. McDowall, 2014) suggests that energy system integration research can involve different disciplinary and strategic approaches: either a relatively limited disciplinary spread with an emphasis on research integration, versus a more diverse disciplinary mix, with less tightly coupled interdisciplinary relations. It is important that this trade-off is recognised and anticipated by interdisciplinary research leaders and managers – and also research funders and assessors. For example, CESI has shown an awareness of this issue in the way it has designed different rounds of its Flex Fund, with an emphasis on openness and diversity in early rounds, and consolidation and integration in later rounds.

## Allow for the extra time and resources involved

As is now widely acknowledged in interdisciplinary studies research, successful interdisciplinary research requires additional time, effort and resources. This needs to be acknowledged in the design and funding of ESI research initiatives, especially in the early stages. As well as disciplinary experts, there is an important role for interdisciplinary leaders and translators – and dedicated effort on integrative knowledge production across specialisms. While there may be less capacity to respond to these challenges in the later stages of research programme, it may be possible to direct flexible funding to support integration – as CESI has shown, and it is important that funders allow use of flexible funds to support integration as well as diversity.

## Recognise the effect of funding arrangements

Unlike some other WES initiatives, CESI is fully funded by a single research Council, the EPSRC. This has some implication for CESI’s research strategy, and how it carries out its interdisciplinary research remit. For example, sole funder status may permit greater Centre discretion in defining interdisciplinary research strategy – but it may also engender less concerted efforts to develop diverse disciplinary participation. As a relative proximate form of research, having a sole research funder based in the engineering and physical sciences is more appropriate for ESI initiatives than more broadly defined WES initiatives.

## Develop a systemic interdisciplinary research strategy

CESI should maintain an interdisciplinary research strategy across *researcher, project, theme,* and *programme* levels. The overall interdisciplinary research strategy should be regularly reviewed. Suggested elements in this strategy are:

* At the *researcher level*, offer interdisciplinary publishing opportunities by negotiating interdisciplinary special issues of high-impact journals. Researchers also value CESI-run events and networks which create a protected space for interdisciplinary exchange.
* At the *project level*, devise and commission projects which deliberately and explicitly combine together different methods and perspectives, with dedicated review processes for assessing the interdisciplinary credentials of proposals.
* At the *workpackage level,* each WP should be designed have senior involvement from different disciplines. Meetings should be regular within WPs, with occasional initiatives across WPs to share best practices. WP progress in interdisciplinary research should be regularly reviewed.
* At the *programme level*, fostering interdisciplinary capacity through ‘seed-corn’ funding, and running workshops and conferences designed can promote centre-wide interdisciplinary exchange. However, developing centre-wide research integration requires a significant commitment to ‘flagship’ projects that are explicitly aimed at involving the majority of the centre’s researchers, disciplines and methods.

Conventional research metrics, such as journal prestige or citation patterns are less appropriate for assessing interdisciplinary research. Other forms of assessment should also be used, such as impact case studies, interdisciplinary output counts, and evidence of follow-on funding.

## Develop best practice across the energy research community

Alongside senior researchers, research funders and assessors have a critical role in shaping interdisciplinary practices and outcomes. Different forms of research commissioning, funding and design have been adopted for different initiatives within the UK’s WES research portfolio, and there is now a considerable body of experience of operating WES and ESI research centres and initiatives. There is an opportunity to review the effectiveness of these different forms, and facilitate regular exchange between different initiatives.

Research carried out for this project suggests that many of the challenges faced by CESI closely resemble those confronted other interdisciplinary centres – reflecting the similar aims of such centres, and the wider structural origins of the challenges they face. Recent steps have been taken to establish links across different initiatives, but these are not yet well embedded in the strategies and practices of the UK’s interdisciplinary energy research community.

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**Annex 1: Assessing CESI’s interdisciplinary character**

**Introduction**

Winskel (2018) offered a framework to comparatively assess whole systems interdisciplinary research centres, using four characteristic elements of such research: diversity, flexibility, integratedness and transdisciplinarity. Using these criteria, assessments can be made of different centres on a consistent basis, so that a ‘high’ flexibility rating indicates that a substantial proportion of the overall centre funds are allocated on an open and competitive basis; a ‘high’ integration rating indicated research processes and outputs that encompassed the majority of the research staff involved; and a ‘high’ transdisciplinarity rating indicates that non-academic stakeholders are significant contributors to the research programme

Research undertaken for this project in 2019, and some follow-up discussions with senior CESI staff in 2020, suggests that by mid-2019 (around mid-way through its five-year research programme 2019) can be tentatively considered to have a medium rating for transdisciplinarity and flexibility, and a low rating for diversity and integration. By late-2020, reflecting changes to the CESI workprogramme, these had shifted to high for transdisciplinarity and medium for diversity, flexibility and integratedness. It should be noted that these assessments are provisional because they apply to an evolving, incomplete research programme.



**Figure 1: Provisional assessment of CESI’s interdisciplinary research status**

(T=transdisciplinarity; D=diversity; F=flexibility; I=integratedeness)

**Transdisciplinarity:** CESI places an emphasis on involving business and local stakeholders. This reflects CESI’s strong relationships with the business sector – a distinctive feature of the CESI research proposal, and also, a growing emphasis on local demonstration and pilots in the CESI research programme. However, there were some suggestions that CESI is less well connected to some energy stakeholders (such as national policymakers) and also that its advisory groups could include more diverse stakeholder perspectives. The work of CESI’s advisory bodies could be also be disseminated more fully across the consortium.

**Diversity:** Early-phase CESI had a relatively low level of disciplinary diversity compared to other WES initiatives. In early 2019, over three quarters of the CESI consortium had an engineering or physical sciences disciplinary background, consistent with an understanding of ESI as a particular form of WES research, oriented to engineering. This disciplinary make-up will condition the forms of whole systems interdisciplinary research that CESI can undertake. There has since been a broadening of the disciplinary base, with early rounds of the Flex Fund used to encourage this. At the same time, greater disciplinary diversity will present additional research integration challenges.

**Integration:** As also seen in other similar centres, CESI has faced challenges in establishing Centre-wide integrative research. Despite some successful initiatives at project and workshop scales, establishing integrative working within and across workpackages has taken longer than anticipated. Thinly spread resources, inconsistent workpackage leadership, geographic dispersion and short term contracts for some research staff have all contributed to these challenges. CESI has taken steps to promote more integrated working across the centre, including directing later round Flex Funds to integrative research driven by existing consortium members.

**Flexibility:** Funding in CESI core and flex activities are spread thinly, and like other similar centres, the Centre has faced a trade-off between openness and integration. At the time of our fieldwork, CESI had commissioned one round of Flex Fund projects; the emphasis in Round 1 was on bringing in new research teams and disciplines. Later Flex Fund rounds have placed greater emphasis on existing members of the CESI consortia and strengthening research integration. However, CESI Flex Fund projects are relatively small and short term, raising additional challenges for the coherence and integratedness of the research programme.

**Appendix 2**

List of Participants at Workshop 2: Researcher Perspectives on Energy System Integration Research, ECCI Edinburgh, 24th June 2019.

1. Merlinda Andoni, Research Associate, Heriot-Watt University
2. Laura Brown, Centre Manager, EPSRC National Centre for Energy Systems Integration
3. Christian Calvillo, Research Associate, University of Strathclyde
4. Chris Dent, Reader in Industrial Mathematics, School of Maths, University of Edinburgh
5. Rebecca Ford, Research Director for EnergyREV, University of Strathclyde
6. Stuart Galloway, Processor of Electrical Engineering, University of Strathclyde
7. Geoffrey Hammond, Professor Emeritus, University of Bath
8. Matthew Hannon, Senior Lecturer, University of Strathclyde
9. Gareth Harrison, Professor and CESI Associate Director, University of Edinburgh
10. David Jenkins, Associate Professor and CESI Co-Investigator, Heriot-Watt University
11. Michael Kattirtzi, Research Fellow, University of Edinburgh
12. Ragne Low, Energy and Climate Change Directorate, Scottish Government
13. Scott Milne, Head of Insights, Energy Systems Catapult
14. Alison Norton, CESI Research Support Officer, Newcastle University
15. Peter Pearson, Honorary Professor, Imperial College London
16. Wei Sun, Research Associate, School of Engineering, University of Edinburgh
17. Phil Taylor, Director of CESI and Head of Engineering, Newcastle University
18. Britta Turner, Research Associate, Durham University
19. Sara Walker, Professor and Associate Director of CESI, Newcastle University
20. Rob Westaway, Senior Research Fellow, University of Glasgow
21. Charlie Wilson, Reader, Tyndall Centre for Climate Change Research, University of East Anglia
22. Mark Winskel, Senior Lecturer, University of Edinburgh
23. Alec Waterhouse, Head of Modelling, BEIS, UK Government

**Appendix 3**

List of attendees at Workshop 3: Stakeholder Perspectives on Energy System Integration Research, Technology and Innovation Centre, University of Strathclyde, 28th January 2020.

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| John | Agbonrofo | University of Strathclyde |
| Oluwafisayo | Alabi | University of Strathclyde |
| I Safak | Bayram | University of Strathclyde |
| Ali El Hadi | Berjawi | Newcastle University |
| Jonathan | Bowes | University of Strathclyde |
| Ruben | Bravo | University of Edinburgh |
| Laura | Brown | EPSRC National Centre for Energy Systems Integration |
| Eric | Brown | Energy Systems Catapult |
| Susan | Brush | Strathclyde University |
| Christian | Calvillo | University of Strathclyde |
| Hannah | Chalmers | University of Edinburgh |
| Brian | Davison | Edinburgh Napier University |
| Kumar Biswajit | Debnath | Heriot-Watt University |
| Branka | Dimitrijevic | University of Strathclyde |
| Jonathan | Fallman | University of Strathclyde |
| M Emad | Farrag | GCU |
| Christina | Francis | UoE |
| Daniel | Friedrich | University of Edinburgh |
| Kelly | Gavin | Scottish Government |
| Kelly | Gavin | Scottish Government |
| Paul | Gilbert | Zero Waste Scotland |
| Horacio | Gonzalez | Hunter Centre for Entrepreneurship |
| Matthew | Hannon | University of Strathclyde |
| Chuantong | Hao | University of Edinburgh |
| Trevor | Hardcastle | Frontier Technical |
| Graeme | Hawker | University of Strathclyde |
| David | Jenkins | Heriot-Watt University |
| Nick | Kelly | Energy Systems Research Unit |
| Desen | Kirli | University of Edinburgh |
| Richard | Knight | University of Strathclyde |
| Mila | Koskinen | Scottish Government |
| Allan | Love | Doosan |
| Natasha | Madeira | Energy Technology Partnership |
| Serguey | Maximov | University of Edinburgh |
| Christopher | McMahon | University of Strathclyde |
| Michael | Millar | Hoare Lea |
| Saeed | Mohammadi | University of Strathclyde |
| Ravi | Pandit | University of Strathclyde |
| Sandhya | Patidar | Heriot-Watt University |
| Watson | Peat | SP Energy Networks |
| Gareth | Powells | Newcastle University |
| Jonathan | Radcliffe | University Of Birmingham |
| Jen | Roberts | University of Strathclyde |
| James | Robertson | University of Edinburgh |
| Jamie | Robinson | Scottish Enterprise |
| Sarah | Sheehy | National Centre for Energy Systems Integration (CESI) |
| Zoe | Shipton | University of Strathclyde |
| Alessa | Sierra | The University of Edinburgh |
| Charlotte | Stamper | Zero Waste Scotland |
| Charlotte | Stamper | Zero Waste Scotland |
| Iain | Struthers | University of Edinburgh |
| Phil | Taylor | Newcastle University |
| Camilla | Thomson | University of Edinburgh |
| Simon | Tricker | Urban Tide |
| Obinna | Unigwe | University of Edinburgh |
| Gerrit | van der Molen | Industrial Systems and Control |
| Stephen-Mark | Williams | Energy Technology Partnership |
| Jin | Yang | University of Glasgow |

1. Corresponding author; email: mark.winskel@ed.ac.uk [↑](#footnote-ref-1)
2. Ragne Low, University of Strathclyde (project Co-I) left the project in Jan 2019, following her departure from the University of Strathclyde. Dr Antti Silvast, University of Durham (project PDRF) left the project in May 2019 following his departure from the University of Durham. Dr Michael Kattirtzi, University of Edinburgh was employed as project PDRF between May and June 2019. The project team (Winskel, Hannon and Kattirtzi) continued to work on the project during the no-cost extensions, with support from Professor Karen Turner and Dr Oluwafisayo Alabi at the University of Strathclyde. [↑](#footnote-ref-2)